The BIODIVERSITY *of a* PEAT SWAMP Forest in Sarawak

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PREFACE

With the campus backing into an extensive peat swamp forest, who better to study the biotic diversity of these little known ecosystems than us?

For the last decade, many of us waded through the peat swamps, sampling, observing and noting the ecology of a virtually unknown ecosystem. Here, in arguably the least understood of Borneo's forested habitats are annelid worms that climb saplings, fishes that live in the shallows and drown if placed in a few centimetres of water, and lizards that are adept in living and breeding in habitats off water. Also represented in these swamps are a host of very diverse organisms, from trilobite beetles to mouse deer, and from cat geckos to peat-swamp adapted crabs. These results, compiled from these observations that use a variety of approaches, are assembled together into this modest volume, to commemorate the 10th year of establishment of Sarawak's first university.

In producing this volume, we are grateful to the authors for their contributions, and the reviewers: Stuart James Davies, Tan Heok Hui, Robert Frederick Inger, Boo Liat Lim, Kelvin Kok Peng Lim, Peter Kee Lin Ng and Navjyot Sodhi. To Peter Kee Lin Ng, we are grateful for writing an introductory piece.

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April 2006.

THE FORGOTTEN WORLD OF PEAT SWAMPS

Peat swamps hold a special fascination for me. When I first embarked on studying the aquatic animals of peat swamp forests of the region over a decade ago, the general consensus was that these "extreme" habitats were species-poor and not very interesting for scholars of biodiversity. A forest of dense low vegetation, constantly waterlogged, with a substrate which is very unstable and oftentimes, impossible to walk, and worse of all, overflowing with disgusting water that looks black under reflected light, surely cannot house anything of value. Imagine having to live in such a world … where the ground is nothing more than loose decaying vegetation, the water is tea-coloured and the pH can reach as low as 4 (highly acidic due to the sulphuric acid)! But you can never tell a book by its cover. Within the dreary forest and in the putrid-looking waters, in fact, lives an amazing community of plants and animals with fantastic adaptations. In our studies in Peninsular Malaysia and Sarawak in the early 1990s, so many new and rare species of fish, crustaceans and other animals were discovered that we were literally "overwhelmed". How could it be that peat swamps still had such a substantial "undiscovered" biodiversity? The reason is simple – most previous workers simply had not "really gone into the swamps", merely believing what books had previously stated that the swamps were species-poor and giving them a miss. Over the last decade or so, an increasing number of workers; "crazy scientists" who were prepared to brave this harsh habitat and enter its realm to sample and study its denizens, have shown that peat swamps are an amazing ecosystem, teeming with species. Peat swamps are today, regarded as a habitat under very serious threat. Not only is it threatened by development and drainage schemes, perhaps an even more pervasive danger is ignorance. These swamps are not the leech and mosquito-infested or malaria-ridden habitats many ill-informed people make them out to be. They are vital not only for biodiversity but also to nullify catastrophic floods and in times of drought, ameliorate the terrible effects. Malaysia, notably Sarawak, has one of the most extensive peat swamp habitats in Southeast Asia and the world, and it is very heartening to read about the present effort to study and conserve a small patch of swamp so near the historical city of Kuching. As the researchers themselves realise, they are but scratching the surface – more – much more remains to be discovered. But every major exercise needs the first step. Their effort is a significant first step to better documenting Sarawak's much maligned, much neglected and often forgotten world of the peat swamp! I certainly look forward to reading about their discoveries – both present and future.

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REVIEW OF PEAT SWAMP FORESTS IN SARAWAK

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ABSTRACT.– Peat swamp forests have been logged or exploited at a commercial scale since 1946. A total of 1.6 million hectares of peatland remains in Sarawak, the largest in Malaysia. These forests contain several valuable timber species, including Ramin *(Gonystylus bancanus),* Alan *(Shorea albida),* Meranti Buaya *(Shorea uliginosa),* Jongkong *(Dactylocladus stenostachys),* Nyatoh (*Palaquiuum* spp.), Kapur *(Dryobalanops rappa),* Sepetir *(Copaifera palustris),* Jelutong *(Dyera lowii)* and Geronggang Padang *(Cratoxylon rappa)*. The diversified plant species and microhabitats of peat forests can be classified into six concentrically zoned phasic communities. The floristic structures and composition of logged over peat swamp forest particularly at Stapok Forest Reserve, Batu Kawa and Universiti Malaysia Sarawak Campus at Kota Samarahan have been described. The silvicultural treatment which stimulate the growth of the residual stand has been restrictedly implemented in Sarawak due to its high cost of operation. To date, vast areas of peatland have been successfully converted for agricultural purposes on large scale, including for plantations of oil palm, sago, rubber, cocoa, coconut and other short term crops. The rate of conversion of these forests into oil palm plantation in particular is extensive and is proceeding at an alarming rate.

KEYWORDS.– Peat swamp forests, deforestation, Sarawak, Malaysia.

INTRODUCTION

Sarawak has the largest peat land (by definition, comprising 65% organic matter) in Malaysia, which occupy an area of about 1.66 million hectares and constitutes 13% of the total land area in the state (Wong, 1991). The soil is distributed at the lower stretches of main river coarse (basin peats) and poorly drained interior valleys (valley peats), and generally occurs between the lower courses of the main rivers such as Batang Saribas, Batang Lupar, Batang Baram, Batang Rajang and its distributaries. Peat soil is generally divided into two major types such as shallow peats (50–150 cm) and deep peat (> 150 cm). Deep peat soils extensively cover more acreage than shallow ones, contributing about 90% of the total acreage of peat soils. The Sibu Administration Division contributes the largest area, followed by Sri Aman, Miri, Kota Samarahan, Sarikei and Bintulu. Administration Divisions of Kuching has the smallest peat area- total land: 23,049 ha. However, statistics from the Forestry Department show that 683,600 ha is gazetted as Permanent Forest; the remainder is State Land. By 1979, almost all peat swamp forest had been licensed for timber extraction (Lee, 1981). Nonetheless, peat swamp forest is perhaps the most heavily exploited and least known scientifically (Whitmore, 1995), and is the first forest type to be logged in Sarawak, primarily due to their easy access and the occurrence of the highly valuable timber species, such as Ramin *(Gonystylus bancanus).* The commercial exploitation of this forest on a large scale was started in 1946 by the British government (Ngau et al., 1987). The first mechanical operations started in 1947. Timber was exported to Great Britain in the early 1950s, and in the subsequent 15 years, British import alone amounted to an average 3 million cu. feet of *G. bancanus* annually. Other commercial species are Alan *(Shorea albida),* Meranti buaya *(Shorea uliginosa),* Jongkong *(Dactylocladus stenostylus),* Nyatoh (*Palaquium* spp.), Kapur *(Dryobalanops rappa),* Sepetir *(Copaifera palustris),* Jelutong *(Dyera lowii)* and Geronggang padang *(Cratoxylon glaucum)* (FAO, 1974; Giesen, 1990; Lee, 1991). Early logging operations were based on putative 60 year rotation, but in the 1970s this figure was revised to 45 years. The minimum girth limits may vary slightly between concessions but generally were 106 cm over bark for Ramin, 140 cm over bark for Kapur, Jongkong and Sepetir, and 148 cm over bark for all other species (Lee, 1992). It was predicted that all peat swamp forests would be logged before the year 2000. However, exploitation of mixed swamp forest and Alan forest reached its peak in 1981 (Lee, 1981). Deforestation has been frequently followed by legal disputes land settlement, systematic conversion to agricultural lands, illegal encroachment or squatters and shifting cultivation. At present, no intact peat swamp forest survives in Sarawak as a result of uncontrolled exploitation or extensive harvest and convertion to agricultural areas or other forms of land use. The remaining unlogged patch is included in the Samunsam Wildlife Sanctuary, Lundu.

Ecological succession is relatively slow and subtypes of this vegetation are hard to recognise and generally considered as logged over or degraded mixed peat swamp forest.

VEGETATION TYPES IN PEAT SWAMPS

Zonation is marked, perhaps uniquely so, in peat swamps of Sarawak and Brunei (Whitmore, 1984). Anderson (1961, 1963) classified six concentrically zoned phasic communities, although all are not necessarily present in any given area. This classification was primarily based on topographic/edaphic factors and successional stages. These forest associations and their descriptive characteristics and extent in Sarawak are illustrated in Table 1. There is a progression of the associations or communities from the mixed peat swamp forest (PC1) at the edges and followed by PC2 (Alan forest), PC3 (Alan Bunga forest) and PC4 (Padang forest). At the centre of highly developed swamps, PC5 and stunted vegetation of PC6 (Padang Paya forest) are found. These forest associations, particularly PC3 and PC6, can be easily recognised, PC5 and Padang Paya forest (PC6) comprising stunted vegetation at the centre of the peat swamp. These forest associations, particularly PC3 and PC6 can be recognized and delineated on conventional aerial photographs. Concentric zonation of plant communities may be observed where the stunted Padang Paya pole community occurs on the elevated centre of convex peat domes, and the commercially important Ramin *(Gonystylus bancanus)* and Terentang (*Campnosperma* spp.) occupy the dome margins. The swamp margins feature some of the tallest trees in the tropics, with some reaching 80 m. These are harvested for timber. The relative homogeneity within peat swamp forest types can possibly be explained partly by the oligotrophic soil characteristics of peat swamps through localized distribution of complex organic compounds and major and trace minerals (Brünig and Drostes, 1995).

Brünig (1969) used a different system to classify nine types of peat swamp forest, according to successional status and local species composition, while the Sarawak Forestry Department uses three operational subdivisions for practical management purposes, namely:

1. Mixed swamp, which has six main commercial taxa, Ramin *(Gonystylus bancanus:* Jongkong, *Dactylocladus stenostachys:* Jelutong *(Dyera polyphylla):* Sepetir *(Copaifera palustris):* Kapur *(Dryobalanops rappa)* and Meranti *(Shorea* spp.);
2. Alan forest, which is dominated by virtually pure stands of *Shorea albida;* and
3. Padang forest, which are located on poorer sites and have a high incidence of stunted trees; and which are therefore of limited production potential (Lee, 1981).

TABLE 1: Anderson's phasic communities (PC) of concentric forest associations within coastal basin peat swamp of Borneo. Sources: [1]Anderson (1961); [2]Lee (1992).

[1]Forest Association	[2]Area (ha)	Descriptive characteristics
PC1.*Gonystylus–Dactylocladus – Neoscrotechinia* (Mixed swamp forest)	1,174,000	Found at peat swamp margins, with structure and physiognomy similar to lowland dipterocarp evergreen rain forest on mineral soils; uneven canopy with dominants attaining 40–45 m; 120–150 tree species ha-1 epiphytes and climbers abundant; *Shorea albida* absent.
PC2. *Shorea albida–Gonystylus–Stenonurus* (Alan Batu forest)	27,000	Similar to PC1 but dominated by scattered, large (> 3.5 m girth) trees of *Shorea albida* (Alan); *Stemonurus umbellatus* indicator species.
PC3. *Shorea albida* (Alan Bunga forest)	76,000	Even upper canopy at 50–60 m in height, dominated by Shorea albida with 70 – 100 trees ha^{-1} of this species alone; middle story commonly absent; moderately dense understory; *Pandanus andersonii* forms dense thickets in shrub layer, climbers and epiphytes rare.
PC4.*Shorea albida–Litsea– Parastemon* (Padang Alan forest)	41,000	Dense, even canopy at 30–40 m composed of relatively small-sized (<1.8 m DBH), trees which give the forest a pole-like and xerophytic appearance; *Shorea albida* density of >400 trees ha^{-1}; small, prostrate shrubs *(Euthemis minor* and *Ficus deltoidea* var. *motleyana)* indicator species; herbs, ferns, epiphytes and climbers rare or absent.
PC5. *Tristania–Palaquium – Parastemon*	NA	Typically found in central domes of peat swamps; narrow transitional forest between PC4 and PC6; dense, even, closed canopy at 15 – 20 m with high density (850–1,250 stems ha^{-1}) of small-sized trees; the layer rare and absent.
PC6. *Combretocarpus – Dactylocladus* (Padang Paya forest)	37,000	Found in central domes of peat swamps; resembles open savanna woodland with stunted, xeromorphic trees; patchy shrubs layer present; pitcher plants (*Nepenthes* spp.) and epiphytic ant-plants *(Myrmecodia tuberosa* and *Lecanopteris sinuosa)* indicator species.

LOGGED OVER PEAT SWAMP FOREST

Logging has been carried out manually in peat swamp forest in the past. In generally flat terrain, rectangular logging compartment or blocks of 200 m wide and 300 m deep were demarcated. Within each logging compartment, two skid trail systems are constructed to reach the back of the compartment. Trees are felled and cut into merchantable length and hauled out from the felling area to the landing wooden sleigh using manpower. The sleigh is locally known as "kuda-kuda", and in fact, the whole system of logging in the peat swamp forest is commonly referred to as "kuda-kuda system". Damage to the residual stand is minimized as a result of the manual system of logging. Logs are then lifted onto log-ramps at the landing from where they are loaded onto rail carts and transported to the log pond.

Table 2 shows an example of floristic structure and composition of logged over peat swamp forest. The only remaining patch is at Batu Kawa in Kuching with several forms of development in its vicinity. The forest was logged a few years ago and contain numerous species and are irregularly storied. Ramin *(Gonystylus bancanus),* the best known timber species which is in high demand in developed countries is scarce in this mixed swamp forest. The dominant species are *Dryobalanops rappa* (Iv = 23.50), *Dyera polyphylla,* the protected species, (Iv = 14.18), *Sindora leicarpa* (Iv = 13.23), *Blumeodendron tokbrai* (Iv = 12.70) and *Ganua motleyana,* the protected species, (Iv = 11.80) (Ipor and Mustafa, 2001). Other species such as *Shorea pachyphylla* (Iv = 9.77), *Copaifera palustris* (Iv = 9.17), *Alstonia spatulata* (Iv = 7.68), *Xylopia corriifolia* (Iv = 6.63), *Elaeocarpus marginatus* (Iv = 6.47), *Neoscortechinia kingii* (Iv = 6.13), *Planchonella maingayi* (Iv = 5.89) and *Xanthophyllum stipitatum* (Iv = 5.31) are also abundant. Jongkong *(Dactylocladus stenostachys)*, the common species in this forest type was not found in this particular area. Other characteristic tree species are *Shorea albida, Palaquium* spp., *Litsea* spp., *Shorea scabrida* and *Eugenia* spp., jelutong paya *(Dyera lowii),* meranti buaya *(Shorea uliginosa),* semayur *(Shorea inaequilateralis),* geronggang putih *(Cratoxylon glaucum)* and rengas *(Melanorrhoea).* Pulai *(Alstonia)* swamp is scattered and occupied considerable areas.

The estimated above - ground biomass and leaf area index are 711.2 t/ha and 5.29 t/ha, respectively. *Sindora leiocarpa* has the highest biomass value followed by *Dryobalanops rappa, Copaifera palustris, Shorea pachyphylla, Parishia maingayi, Melanorrhoea beccarrii* and *Dyera polyphylla.* The lowest value of biomass is for *Santaria laevigata, Polyalthia sclerophylla, Knema intermedia* and *Calophyllum hosei.*

Silviculture operations in the peat swamp forest.- The first silviculture operation is introduced within a year of logging. The treatment is carried out by poisoning damaged and badly shaped trees of all species 30 cm diameter at breast height or diameter above buttress. Jelutong *(Dyera lowii)* is not allowed to be poisoned. The purpose of the treatment is mainly to stimulate the growth of the residual stands. It is only 10–15 years after logging that the second silvicultural operation is carried out in the regenerating forest. This operation is referred to as diagnostic sampling and is intended to assess the silvicultural condition of the forests determined by the level of stocking, the species composition and the degree of competition. Analysis of data collected during diagnostic sampling will give a guide on the need for further silvicultural treatment and the nature of the treatment. Treatment may involve poisongirdling to further stimulate the regenerating forest if it is highly stocked, or enrichment planting if the forest is found to be inadequately stocked. Following diagnostic sampling, yield plots are established within the regenerating forest to monitor the growth of the stand and to determine the timing of the next cut. While the felling cycle of the peat swamp forest is tentatively set at 45 years, the time of subsequent cuts is flexible and is dependent on the rate of growth of the forests. Extensive diagnostic sampling carried out so far reveals adequate to heavy stocking of desirable species which are well distributed. There is evidence of stagnant of growth especially of light-demanding species 10–15 years after logging. Silvicultural treatment aimed at eliminating vegetation competing with potential crop trees is carried out to stimulate the growth of such fast-growing species as Geronggang (*Cratoxylon* spp.), Kapur Paya *(Dryobalanops rappa),* the Swamp Merantis (*Shorea* spp.) and Jongkong *(Dactylocladus stenostachys).* Ramin *(Gonystylus bancanus)* does not regenerate well in the logged-over forest. Although generally present as advance growth, there are few stems of this species below 20 cm in diameter in most areas 20 years after logging. Ramin trees flower and fruit annually but the resultant seedlings do not seem to be able to compete with other fast-growing species.

In Alan swamp forest, although a high percentage of Alan seedlings are present after logging, they are quickly submerged by competing vegetation; and not all of those that survive may reach merchantable size in time for the next cut. The complete absence of Alan in the sapling and pole-timber sizes is common in recently logged (and unlogged) Alan swamp forests. Fast-growing species like Ako *(Xylopia coriifolia),* Medang (*Litsea* spp.) and Geronggang (*Cratoxylum* spp.) make large gains after logging. Species such as Jongkong *(Dactyocladus stenostachys),* Ketiau (*Ganua* spp.), Semayur *(Shorea inaequilateralis)* with medium rates of growth show about 20% gain in distribution while slower-growing species such as Keruntum *(Combretocarpus rotundatus),* Rengas (*Melanorrhoea* spp.), Nyatoh (*Palaquium* spp.) and Ramin *(Gonystylus bancanus)* decrease in distribution by about 30%.

TABLE 2: Relative density (Rd), Relative frequency (Rf), Relative dominance (RD) and Important value (Iv) of trees species with a DBH of >5 cm in logged over peat swamp forest of the Stapok Forest Reserve, Batu Kawa, Kuching.

Species	Rf	Rd	RD	Iv
Dryobanalops rappa	4.20	4.91	14.38	23.50
Dyera polyphylla	2.34	5.61	6.23	14.18
Sindora leiocarpa	0.47	0.70	12.06	13.23
Blumeodendron tokbrai	4.20	5.61	2.89	12.70

Species	**Rf**	**Rd**	**RD**	**Iv**
Ganua motleyana	3.27	4.91	3.62	11.80
Shorea pachyphylla	1.87	1.40	6.50	9.77
Copaifera palustris	0.47	0.35	8.35	9.17
Alstonia spatulata	2.80	2.81	2.07	7.68
Xylopia corriifolia	2.34	2.46	1.84	6.63
Elaeocarpus marginatus	3.27	2.81	0.39	6.47
Neoscortechinia kingii	2.80	2.46	0.87	6.13
Planchonella maingayi	2.34	2.46	1.10	5.89
Parishia maingayi	0.47	0.35	4.70	5.51
Xanthophyllum stipitatum	2.34	2.46	0.52	5.31
Xerospermum muricatum	2.80	2.11	0.29	5.19
Shorea albida	1.87	1.75	1.51	5.13
Melanorrhoea beccarrii	0.47	0.35	3.95	4.76
Aromadendron nutans	2.34	1.75	0.44	4.53
Palaquium ridleyi	1.40	1.40	1.65	4.45
Lithocarpus pseudokunstleri	1.40	2.11	0.81	4.32
Shorea platycarpa	1.40	1.40	1.20	4.00
Palaquium walsuraefolium	0.93	0.70	2.33	3.97
Xanthophyllum ellipticum	2.34	1.40	0.17	3.91
Ardisia polyactis	1.87	1.75	0.27	3.89
Cyathocalyx biovulatus	1.40	1.75	0.36	3.52
Palaquium pseudorostratum	0.47	0.35	2.64	3.46
Dacryodes macrocarpa	1.40	1.75	0.28	3.44
Dillenia pulchella	0.93	0.70	1.79	3.42
Litsea gracilipes	1.87	1.40	0.14	3.41
Horsfieldia crassifolia	1.40	1.75	0.21	3.37
Dialium laurinum	0.93	1.40	1.01	3.35
Myrsine multibracteata	1.40	1.40	0.25	3.06
Timonius flavescens	0.93	1.75	0.32	3.01
Cinnomomium iners	1.40	1.05	0.50	2.95
Litsea turfosa	0.93	0.70	1.24	2.87

Species	Rf	Rd	RD	Iv
Gymnocranthera eugeniifolia	1.40	1.05	0.31	2.76
Palaquium leiocarpum	0.93	0.70	1.06	2.69
Shorea scabrida	0.93	0.70	0.97	2.61
Nephelium maingayi	0.93	1.05	0.52	2.51
Eugenia palembanica	0.93	0.70	0.85	2.48
Vatica mangachapoi	0.47	0.70	1.11	2.28
Gonystylus bancanus	0.47	0.35	1.42	2.24
Koompassia malaccensis	0.93	1.05	0.25	2.23
Lithocarpus andersonii	0.93	1.05	0.25	2.23
Mesua beccariana	0.93	1.05	0.09	2.08
Campnosperma coriaceum	0.93	0.70	0.41	2.05
Ilex cymosa	0.93	0.70	0.33	1.97
Prunus turfosa	0.93	0.70	0.28	1.92
Eugenia subsessilifolia	0.47	0.35	1.02	1.84
Eugenia christmannii	0.93	0.70	0.12	1.75
Macaranga caladiifolia	0.93	0.70	0.10	1.73
Elaeocarpus beccarrii	0.93	0.70	0.07	1.70
Elaeocarpus mastersii	0.93	0.70	0.07	1.70
Mangifera havilandii	0.93	0.70	0.07	1.70
Lithocarpus dasystachyus	0.47	1.05	0.18	1.70
Croton oblongus	0.47	1.05	0.10	1.62
Garcinia bancana	0.93	0.35	0.03	1.32
Shorea longiflora	0.47	0.70	0.15	1.32
Tristania obovata	0.47	0.70	0.12	1.29
Glochidion lucidum	0.47	0.35	0.42	1.24
Tetractomia latifolia	0.47	0.70	0.07	1.23
Pometia acuminata	0.47	0.70	0.06	1.23
Garcinia cuspidata	0.47	0.35	0.29	1.11
Pometia pinnata	0.47	0.35	0.24	1.06
Kibatalia borneensis	0.47	0.35	0.21	1.03
Sterculia rhoidifolia	0.47	0.35	0.20	1.02

Species	**Rf**	**Rd**	**RD**	**Iv**
Litsea crassifolia	0.47	0.35	0.18	0.99
Palaquium cochleariifolium	0.47	0.35	0.10	0.92
Melanorrhoea macrocarpa	0.47	0.35	0.09	0.91
Knema kunstleri	0.47	0.35	0.08	0.90
Randia kuchingensis	0.47	0.35	0.08	0.90
Santiria rubiginosa	0.47	0.35	0.07	0.89
Xerospermum accuminatissimum	0.47	0.35	0.06	0.88
Sarcotheca glauca	0.47	0.35	0.06	0.87
Eugenia ochneocarpa	0.47	0.35	0.05	0.86
Eugenia nemestrina	0.47	0.35	0.04	0.86
Ganua pirrei	0.47	0.35	0.04	0.86
Sandorium emarginatum	0.47	0.35	0.04	0.86
Baccaurea bracteata	0.47	0.35	0.03	0.85
Calophyllum hosei	0.47	0.35	0.03	0.85
Calophyllum lowii	0.47	0.35	0.03	0.85
Canthium didymum	0.47	0.35	0.03	0.85
Carallia brachiata	0.47	0.35	0.03	0.85
Cryptocarya densiflora	0.47	0.35	0.03	0.85
Diospyros pseudomalabrica	0.47	0.35	0.03	0.85
Eugenia leucoxylon	0.47	0.35	0.03	0.85
Knema intermedia	0.47	0.35	0.03	0.85
Lithocarpus pusillus	0.47	0.35	0.03	0.85
Litsea firma	0.47	0.35	0.03	0.85
Litsea nidularis	0.47	0.35	0.03	0.85
Litsea paludosa	0.47	0.35	0.03	0.85
Macaranga triloba	0.47	0.35	0.03	0.85
Mezzetia umbellata	0.47	0.35	0.03	0.85
Polyalthia sclsclerophylla	0.47	0.35	0.03	0.85
Santaria laevigata	0.47	0.35	0.03	0.85
Xanthophyllum ramiflorum	0.47	0.35	0.03	0.85

PHYSICAL PROPERTIES OF PEAT SOIL

The description of the properties of peat soil given here is based on the description by Tie and Kueh (1979). The top layer of peat is usually 10–20 cm thick, located at the depth of 10–20 cm and consists mainly of well decomposed organic materials. The subsoils are, however, usually fibric and woody in nature. Such materials provide a poor physical environment for plant growth. Drainage, decomposition and consolidation of surface peat can lead to the formation of mellow, friable soil. This condition will provide little anchorage for tree crops. The woody nature also makes it impractical to carry tillage. Mechanical means are impossible to apply in these fields. There is also little anchorage for tree crops, and in addition, the woody nature makes field tillage impractical. Land preparation is more difficult, and mechanical excavation of drains in particular is a formidable task. The loose, non-cohesive nature of the fibric peat also means that slumping along the side of the drains will be difficult to control. More regular desilting may there be required.

Anderson soils are invariably waterlogged with ground water table naturally at or close to the surface most of the year round. Drainage is therefore a prerequisite for the cultivation of any identified potential crops on this soil type with the exception of sago plants. The values of hydraulic conductivity are generally high, ranging from 28.3 to 87.5 cm per hour (Mailraganam, 1990). This is mainly due to the open structure of peat materials. However, the spongy peat has a high water absorption capacity. As a result, shedding of water from the peat swamps is normally well regulated even though the dome-shaped morphology and the high permeability may suggest rapid radial drainage. This phenomenon of 'stilted groundwater table' means that for effective drainage, field drains must be more closely spaced than what the rapid hydraulic conductivity would suggest. Depending on the degree of decomposition and compaction, the drawdown effect of the drains on water table is only limited to a belt of 50–100 m on either side (Tie, 1991; Chin and Poo, 1992).

Organic soils have low bulk density (usually less than 0.1g/cc) and low bearing capacity (0.12–0.21 kg/cm2). These physical and low characteristics lead to many problems particularly in road construction and the building of other infrastructures such as houses in sago plantation. Road construction is expensive due to large amount of filling to obtain firm foundation and the intensive maintenance required. Machinery used must be modified to lighter weights and needs wider track to reduce ground pressure so that they can move freely and effectively. Construction of houses and other infrastructure is also more expensive. Thus, it is obvious that sago plantations need more capital than those oil palm plantations in ordinary sandy alluvial soils.

A unique feature of the organic soils is that once drained, they are subject to subsidence. Initial subsidence immediately after drainage is mainly caused by compaction and shrinkage due to the removal of water and the loss of buoyancy.

Subsequently, it is mainly due to decomposition, loss of soluble organic materials as a result of leaching, and burning (a normal practice in any cultivation). The rate of continual subsidence depends largely on the degree of drainage or the depth of water table. It has been recorded in Sarawak that subsidence of deep peat occurred up to 60 cm within the first two years after reclamation (Tie and Kueh, 1979). The rate is reduced to only about 6 cm per annum as a result of subsequent water table at 75–105 cm. The same trend of subsidence was observed at Tanjung Bijat and Lebaan - Bawang Assan DID Schemes in Sarawak (Chin and Poo, 1992). The rate could be as high as 35 cm in the vicinity of the drains. This potential to subside should be seriously considered while designing the water control structures. DID is recommending that all structures in peat should be 'temporary' in nature; pile foundations should be avoided unless peat subsidence can be realistically catered for.

A practical way to minimizing subsidence is therefore through maintaining water table to a level just below the root zone, or field conditions required for mechanisation. Burning also promote subsidence. Subsidence of organic soils may also be minimized by keeping a protective layer of mineral soils over the planting hole.

Over-drainage will increase the rate of subsidence and can also lead to irreversible drying of the organic soil. The resultant dry and hard granules are difficult to re-wet and provide a poor growth medium. Irreversible drying may occur during a prolonged dry period, especially if the water table has been kept low. The problem or over-drainage should be particularly noted in the development and management of peat soils fringing coastal sandy deposits. During prolonged dry spells, the drawdown of water table in such areas may be excessive thus causing a water shortage. Experiences in Kelantan has shown that mere damming drains with drainage control in such areas do not effectively control the water table to the required height (Chin and Poo, 1992).

At the present rate of subsidence, with the presence of drainage systems and cultivation, 150 cm of peat will disappear within 17 years. This does not represent a real loss if the mineral substratum continues to be used. However, soil surveys in Sarawak have shown that many of the peatland are underlain by mineral substrata which are below the present river level. Unless costly measures such as dyking and pumping are practised, reclamation projects may have to be abandoned when the ground surface has subsided below the level of the river. Therefore, sustained usage of peatland for dry-land crops is highly questionable. Alternative utilization of undrained peatland for wetland crops like sago (*Metroxylon* spp) may be more viable. Some of the coastal peat are underlain by mineral substrata which are either above the mean sea level or above the lowest tide level (Chin and Poo, 1992). This characteristic, coupled with the high tidal range along the coast of Sarawak, implies that even after all the peat have disappeared, such areas could still be drained by gravity (at low tides), provided there are bunds and check-gates to keep out the water at high tides.

CHEMICAL PROPERTIES OF PEAT SOIL

Organic soils are highly acidic, with pH ranging from 3.2–4.0. Due to the highly organic nature of the soils, Al toxicity is usually not a problem. Total N level is generally greater than 1%, but C/N ratio is usually high. A high C/N ratio means that immobilization of added N fertilizer may occur initially. Peat soils have relatively high reserve of organic P. However, the level of available P is low, usually less than 100 ppm. The levels of exchangeable bases and trace elements including silica are also very low. Available Cu and Zn in particular are extremely low.

The face values of the analytical results of organic soils expressed on dry weight basis may be misleadingly high. As the bulk density of organic soils is only about one-tenth that of mineral soil, the results for organic soils must be reduced by a similar factor before valid comparisons with mineral soils can be made. In one of the surveys, Tie et al. (1989) highlighted the low inherent fertility of organic soils in relation to sago-growing soils by comparing the values on the basis of volume (Table 3).

Organic soils, especially those of the Anderson Series, are therefore extremely low in levels of macro and micronutrients. Of the major nutrient elements, N and K requirements are particularly high. Generally N requirement, for example, is 30–300% more for crops growing on peat as compared to mineral soils.

Micronutrient deficiencies such as Cu, Zn, Fe and B are also common (except for sago plants) for crops growing on peat. All these nutritional problems have to be solved before crops can be grown satisfactorily on organic soils. For oil palm, for example, the early plantings on deep peat were plagued with nutritional problems like mid crown chlorosis and peat yellow. These were discovered to be due to Cu and Zn deficiency, respectively. Yields improved tremendously when the deficiencies were corrected.

TABLE 3: Properties of the surface layer 90–25 cm of the main sago-growing soils in Mukah and Oya-Dalat areas. Source: Tie et al. (1989).

Property	Daro Series	Bijat Series	Organic Soils
Total N (t/ha)	14.575	7.783	3.730
Exch. Ca (t/ha)	0.315	0.255	0.133
Exch. Mg (t/ha)	1.110	0.368	0.128
Exch. K (t/ha)	0.290	0.268	0.055
Reserve Ca (t/ha)			
Reserve Mg (t/ha)	0.435	0.338	0.255
Reserve K (t/ha)	5.395	6.028	0.213
Reserve P (t/ha)	12.523	14.168	0.155
Avail. P (t/ha)	1.040	0.940	0.123
Morgan's Fe (kg/ha)	0.158	0.075	0.015
Morgan's Mn (kg/ha)			
Moorgan's Cu	345	345	7.5
(kg/ha)	49.5	14.5	1.8
	2.5	2.6	0.2

PEATLAND FOR AGRICULTURE

Good land use has been defined as the avoidance of environmental deterioration and efficient economic utilization for a stated purpose. These two criteria are all the more important in the management of peatland, as forest removal and drainage give rise to drastic changes in peat (compared to mineral) soils, and the high cost of reclamation of peatland makes it increasingly more difficult to utilize this soil type economically. Peat soil has limited suitability for crops due to the multitude of problem such as water logging condition, low fertility, highly acidic conditions, high cost of intensive drainage and irrigation and expensive for mechanization. The alleviation of chemical constraints appears promising, but a number of constraints associated with soil physical properties and water relations need to be overcome. Better diagnostic methods, such as soil testing, need to be developed to more accurately identify nutritional stresses and formulate appropriate fertilizer recommendation. Due to the extensive acreage of peat soils in Sarawak, their importance as an agricultural land resource is recognised. In addition, farmers had no alternative but to farm the organic soils with a range of crops. The earlier general practice in peatland utilization was to allow agriculture in areas which could be permanently drained while other deep peat areas would be left in their natural state for silviculture. Controlled minimal drainage would allow dryland cultivation with minimal deterioration of the peat layer. Sago *(Metroxylon sagu)* grows successfully on unimproved (undrained) peat. During the rubber boom years in the 1910's, some 16,000 ha of peat near Sibu were drained and planted with rubber seedlings. Over the years following the draining of the peat swamps, drastic subsidence has caused the roots to be exposed, making rubber-tapping an arduous task. Most of the rubber stands have leaned over and the water table is above the soil surface most of the time. The low yield coupled with the low rubber price have made rubber uneconomic to maintain.

Pineapples are planted in small scale for the fresh fruit market. Shallow coastal peat is also planted with coconut. Deep peat generally cannot provide sufficient anchorage and leaning becomes a problem at a later stage. Pepper farmers near Sibu grow the crop on deep peat with some success but frequently, mineral soils need to be added as an improver. The main problems encountered are micro-nutrient deficiency, lodging and nematode infection. Sibu farmers also grow vegetables quite successfully in a unique fallow-cropping system and with the use of organic and chemical fertilizers. The practice of burning the cleared vegetation on the plot plays an important role in deacidification, supply of nutrients and partially sterilizing the soil. Sometimes wood ash purchased from local charcoal kilns is used as a cheap liming material. Sawah rice appeared to be a promising crop for undrained peat. However, planting of rice crop sometimes resulted in disappointingly poor harvest due to the problem of empty panicles.

Research by the Agriculture Department of Sarawak, MARDI and PORIM indicates some potential for annuals and short term perennials such as ginger, essential oils, castor oil, legumes (cowpea, groundnut, soya bean and bambara groundnut), maize, sorghum, tobacco, pineapple, sugar cane, sweet potato, tapioca, passion fruit and vegetables. Among the long term perennials, oil palm, dwarf (Mawar) coconut, sago, coffee, lowland rea, cashew nut, pepper, cocoa, annatto, mulberry, clove, nutmeg and fruit trees have good potential. Pineapple has overall advantage over other crops as it does not require liming. Tapioca takes advantage over the excellent physical conditions of drained peat. Legumes in association with *Rhizobia* replenish the soil with nitrogen and are valuable in crop rotations, while tobacco takes advantage of the slow release of nitrogen to maintain the quality requirement of the leaves.

SAGO CULTIVATION

Sago palm is the only perennial tree crop that has given promising performance in deep peat soil. With high adaptation to water logging condition, the farmers have undoubtedly planted sago because of its promising economic returns. Well-managed sago farms would start production 12 years after planting on deep peat. The wet conditions result in maximum girth without any fertilizer application and encourage vegetative growth suckers. The growth of the mother plants can be significantly faster by thinning the unnecessary suckers. As in alluvial soil, sago plants exhibit excellent performance in the flowing water conditions in peatland. Plants grown along the drains closest to the river and its tributaries agronomically performed well and produces longer and bigger stems, which is probably due to the enhancement of nutrient uptake due to the fluctuating water level. However, drastic and excessive drainage of the peat soil has given adverse effect on the growth and production of sago. This is indicated by the delayed formation of trunk with small crown due to dry condition and drastic degradation of peat layer after drainage.

Sago is a hydrophilic plant that can thrive well on the specialized environment of peat soils. This plant has relative persistence and adaptability to these soil types. The dense formation of root system enable it to exploit the root zone more effectively than any other crops (Tie et al., 1987). This plant does not need liming and fertilizer on deep peat of Anderson series. Kuek (1991) found that addition of fertilizer does not result in any significant growth response. No proper drainage is needed so that the water table is sustainably maintained at soil surface level. The cultural practices of sago on deep peat must emphasize on limiting the soil destruction and rate of humidification at the minimal level. This will reduce the subsidence of peat layer. Degradation of peat soils would shorten the lifetime of sago. Maintenance work is kept minimal. Occasional slashing is done to suppress the undergrowth as that of the herbaceous green does not provide adverse effect to the growth of sago palms.

There has been no comprehensive study on the floral composition and its dynamics in sago farms and its vicinity. Farmers usually encourage the development of their farms with selective clearing, felling and protection. These gardens would revert slowly, perhaps over 200–300 years, to the appropriate peat climax vegetation (Anderson, 1963). *Macaranga* spp. and *Shorea* spp. dominated the vegetation due to its rapid establishment. Under the palm canopy, the undergrowth varies from a mixed grass and herbaceous weed flora, the latter frequently dominated by ferns such as *Nephrolepis biserrata, Stenochlaena palustris* and *Lygodium flexuosum.*

OIL PALM CULTIVATION

The availability of powerful tools, equipment and industrial technology can readily overcome natural obstacles to development. In recent years, cultivation of oil palm and sago palm has been rapidly expanded in peatland areas. Other crops such as coffee, cacao, rice, illenuts, pineapples, a variety of vegetables and even rubber are considered good prospects. The expanding cultivation of estate crops are mainly in Bintulu, Samarahan and Sri Aman Divisions, utilizing deep peat. Before planting, localized soil compaction is carried out using heavy machinery. The main fertility consideration is the application of macro and micronutrients. Proper and effective drainage system seems to be a key factor in ensuring the success of cultivation on lowland peat.

CONSERVATION STRATEGIES

The possible development and land-use of potential areas should be based on an evaluation of options in which reclamation for agricultural development and conservation (i.e., protection of the original or natural situation in order to preserve biodiversity and the major servicing function of the ecosystem) go side by side in a mosaic of land-use. Such an integrated approach to development and land-used have often been neglected in Malaysia. Notably the large-scale development projects pertaining to transmigration have commonly been planned without due consideration of ecological factors and the potential for sustainable land-use. As a consequence, many transmigration projects in low-lying land areas can be considered as economic errors because they fail to yield the expected agricultural return while having ruined the ecological service functions of the original areas. The implication of peat soil utilization has been controversial after several failures in reclaiming these soils for successful agriculture activities. This is mainly due to lack of meticulous planning and co-ordination as well as in rigorous management. Development of peat land for agricultural purpose must take into account the ecological make-up of the original state.

Within Sarawak, the utility of peat lands is linked to the conflicts of interest and competition for the use of peat swamp water. Peat lands have been essentially identified as a resource for public water supply, forestry and agriculture. As land development projects involve the manipulation of environment, the anticipated impact should be carefully evaluated and weighed against possible benefits in order to avoid undesirable consequences. Agricultural activities have accelerated the impact on the morphological, physical and chemical nature of peat land drainage. Planting of particularly, the dry crops needs clearing, drainage and irrigation. Peat areas where agricultural development established experiencing excessive drainage and drastic irrigation which promote surface runoff, increasing the humidification of the peat, reduce the ground water in the peat. These activities can be detrimental to the preservation of the peat land as a water source. In addition, cultivation of dry crops needs substantial fertilization to become productive. Deacidification through liming is also another prerequisite for most crops grown in peat (Kueh, 1977). Both fertilization and deacidification caused the adverse effect to the water quality.

Keeping permanent forest estates has proved promising for economic returns through timber production. After selective logging of timber, the forest are left to regenerate naturally. However, regeneration may be slow and without artificial planting, timber species such as Ramin, *Gonystylus bancanus* may not re-establish by themselves. Lee (1991) reported that mixed swamp forest at the fringes of the peat swamps has a high potential to naturally regenerate after logging but not the Alan swamp areas. Additionally, Lee (1992) also suggested that agricultural activities such as planting sago can be intensified on the degraded areas where there is low or no stocking of forest trees.

Sago palm with the ability to adapt to undrained, acid peat soils of low nutrient status is probably the best alternative and acceptable to the conservation activities. It causes little environmental disturbances. Sago palm can be treated as proponents of agroforestry and conservation of forest and swamp environments. Conservation of sago palm or increasing the sago acreage will directly contribute to the conservation of peat lands and subsequently result in sustainable source of water for public ultilization.

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